

PRESENTACION ORAL

The baryonic mass assembly of low-mass halos in a Λ -CDM Universe

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Abstract. We analyse the dark, gas, and stellar mass assembly histories of low-mass halos ($M_{\text{vir}} \sim 10^{10.3} - 10^{12.3} M_{\odot}$) identified at redshift $z = 0$ in cosmological numerical simulations. Our results indicate that for halos in a given present-day mass bin, the gas-to-baryon fraction inside the virial radius does not evolve significantly with time, ranging from ~ 0.8 for smaller halos to ~ 0.5 for the largest ones. Most of the baryons are located actually not in the galaxies but in the intrahalo gas; for the more massive halos, the intrahalo gas-to-galaxy mass ratio is approximately the same at all redshifts, z , but for the least massive halos, it strongly increases with z . The intrahalo gas in the former halos gets hotter with time, being dominant at $z = 0$, while in the latter halos, it is mostly cold at all epochs. The multiphase ISM and thermal feedback models in our simulations work in the direction of delaying the stellar mass growth of low-mass galaxies.

Resumen. Analizamos las historias de ensamblaje de la masa oscura, gaseosa y estelar de halos de baja masa ($M_{\text{vir}} \sim 10^{10.3} - 10^{12.3} M_{\odot}$) identificados a corrimiento al rojo $z = 0$ en simulaciones numéricas cosmológicas. Nuestros resultados indican que, para halos en un dado rango actual de masa, la fracción de gas respecto de bariones dentro del radio virial no evoluciona significativamente con el tiempo, extendiéndose desde ~ 0.8 para los halos pequeños hasta ~ 0.5 para los más masivos. En realidad, la mayor parte de los bariones no está localizada en las galaxias sino en el gas intra-halo; para los halos más masivos, el cociente de masas entre el gas intra-halo y la galaxia central es aproximadamente el mismo a todo corrimiento al rojo, z , pero, para los menos masivos, éste se incrementa fuertemente con z . En los primeros, el gas intra-halo aumenta su temperatura con el tiempo, siendo la componente caliente dominante a $z = 0$, mientras que en los segundos, la componente gaseosa es predo-

minantemente fría en toda época. En nuestras simulaciones, los modelos de ISM multi-fase y *feedback* térmico favorecen el retraso del crecimiento de la masa estelar en galaxias de baja masa.

1. Introduction

Cosmological simulations of structure formation constitute fundamental tools for studying the problem of galaxy evolution through cosmic epochs. In the Λ cold dark matter (CDM) paradigm, more massive halos assemble by the hierarchical aggregation of smaller ones (upsizing). Galaxies form from the gas trapped inside the potential well of these halos and are affected, in a complex way, by different astrophysical processes such as gas cooling, star formation, supernova (SN) feedback, and chemical enrichment, among others. In this context, a current challenge for observational and theoretical studies is the understanding of the relation between the halo mass aggregation histories and the evolution of the baryonic matter hosted by these halos, both in galaxies and in the intergalactic medium around them.

The relation between the stellar (M_*) and virial (M_{vir}) mass of galaxies has been the subject of many empirical and semi-empirical studies in the local Universe and at higher redshifts (see e.g., Firmani & Avila-Reese 2010, Avila-Reese & Firmani 2011). From a theoretical point of view, current models and simulations of low-mass galaxies evolving in a Λ -CDM universe seem to predict a too early M_* assembly than what observations suggest (Avila-Reese et al. 2011 and more references therein). In De Rossi et al. (2013; DR+13), we analysed the halo, baryonic and stellar mass assembly of galaxies by means of cosmological numerical simulations. We have found that the upsizing trend of halo mass growth seems to be reverted to a moderately downsizing trend in the case of the galaxy baryonic/stellar mass assembly, though the latter trend is weaker than the observed one. Here, we present results from these simulations regarding the evolution of the intrahalo gas, which is affected by the halo capture, heating and cooling mechanisms as well as by the galaxy SN-driven outflows.

2. Simulations

We performed numerical simulations by using the chemical code GADGET-3 (Scannapieco et al. 2008), which includes treatments for metal-dependent radiative cooling, stochastic star formation, chemical enrichment and SN feedback. We assumed the concordance Λ -CDM cosmology with $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, $\Omega_b = 0.045$, a normalisation of the power spectrum of $\sigma_8 = 0.9$ and $H_0 = 100 h \text{ km s}^{-1} \text{ Mpc}^{-1}$ with $h = 0.7$. The simulated volume corresponds to a cubic box of a comoving $10 \text{ Mpc } h^{-1}$ side length. The masses of dark matter and initial gas-phase particles are $5.93 \times 10^6 \text{ M}_\odot h^{-1}$ and $9.12 \times 10^5 \text{ M}_\odot h^{-1}$, respectively (S230) and $2.20 \times 10^6 \text{ M}_\odot h^{-1}$ and $3.40 \times 10^5 \text{ M}_\odot h^{-1}$, respectively (S320). See De Rossi et al. (2010, 2012) and DR+13 for more details about the simulations.

3. Results

We analyse the mass aggregation histories (MAHs) associated to halos identified at $z = 0$ by separating them into four mass bins accordingly to their $\log(M_{\text{vir}}/M_{\odot})$: < 10.5 , $10.5 - 11.0$, $11.0 - 11.5$, ≥ 11.5 . As discussed in detail in DR+13, the average MAHs are in rough agreement with those derived from the Millennium Simulations, though for the lower-mass halos, at high z 's, our halos are systematically less massive. The latter is due to the effects of baryons on the total halo mass. In general, both the Millennium Simulations and our runs show a later M_{vir} assembly as more massive are the halos (upsizing). We also analyse the *total* stellar and baryonic masses inside the virial radius (R_{vir}) and find that they assemble approximately at the same rate as the halo mass. Inside the halos, more than half of the baryons are always in the gas phase at all our scales and at least up to $z \sim 3$. This gas-to-baryon mass fraction ranges on average from ~ 0.8 for low-mass systems to ~ 0.55 for the more massive ones, with little change with z . This means that the lower the halo mass, the less efficient is the system in making stars.

In Fig. 1, left panel, we show the evolution of the ratio of the gas mass in the halo (i.e. outside the galaxy but inside R_{vir}), $M_{\text{gas,h}}$, to the galaxy (stars+gas) mass, M_{gal} , for the four aforementioned mass bins. At $z \sim 0$, the mass in the intrahalo gas is on average $\sim 1.5\times$ larger than the mass in the central galaxy (satellites are typically very small). This ratio is roughly the same at higher z 's for the massive halos, but it significantly increases with z for the less massive halos. In the right panel of Fig. 1, we analyze the evolution of the fraction of this intrahalo gas in warm-hot and cold phases, with a temperature separation of $T = 15000 \text{ K}$. For the lowest-mass halos, the intrahalo gas is mostly cold ($\sim 80\%$) at all z 's, while for the most massive halos, the fraction of warm-hot gas increases with time, from $\approx 30\%$ at $z \sim 3$ to 75% at $z \sim 0$.

4. Discussion

Our cosmological simulation of ~ 300 low-mass galaxies in a 14.3 Mpc-size box shows that the smaller the halo mass, the larger is the total gas-to-baryon mass fraction inside R_{vir} . Therefore, the efficiency in making stars decreases with M_{vir} ; for $M_{\text{vir}} \approx 1 - 3 \times 10^{10} M_{\odot}$, more than 80% of the baryons are in the gas (mostly cold) phase at all z 's. The multiphase ISM and the thermal feedback models introduced in the code seem to work in the direction of avoiding too early and active SF in the low-mass systems.

The simulation shows that most of the baryons in the halos at $z \sim 0$ are located actually in the intrahalo gas, which on average accounts for $\sim 1.5\times$ more mass than in the galaxies (left panel, Fig. 1). This suggests that a significant fraction of the present-day missing baryons are actually located in gas around the galaxies. What is the thermal state of this gas? This depends strongly on the halo mass (right panel, Fig. 1): for the smaller systems, most of the gas is in the cold phase ($T < 15000\text{K}$), while for the larger systems, it dominates the warm-hot phase (up to $\sim 75\%$ on average in halos of $M_{\text{vir}} \approx 3 - 30 \times 10^{11} M_{\odot}$). For the latter, the intrahalo gas significantly warms up with time, as the halo grows and virializes, limiting this the ulterior growth of the galaxy. For the less

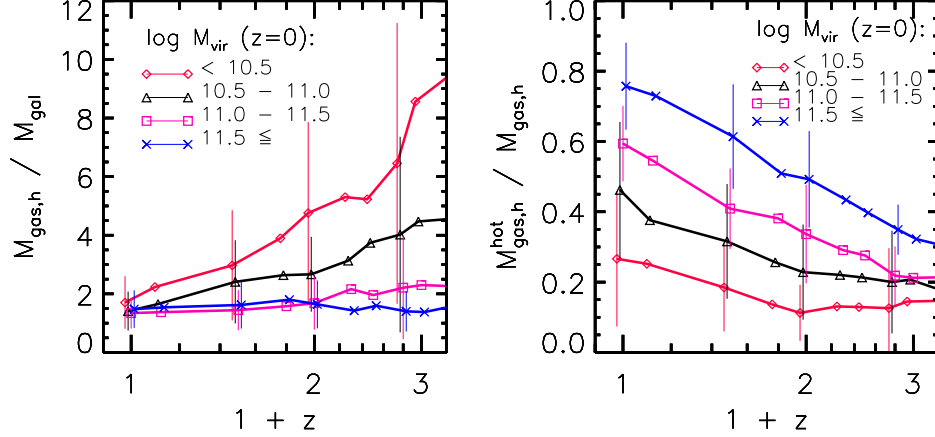


Figure 1. Average intrahalo gas-to-total galaxy mass ratio (left panel) and the fraction of the intrahalo gas in the warm-hot phase (right panel) for four $\log(M_{\text{vir}}/M_{\odot})$ bins defined at $z = 0$ (solid lines): < 10.5 (red diamonds), $10.5 - 11$ (black triangles), $11 - 11.5$ (pink squares) and ≥ 11.5 (blue crosses). Error bars represent 1σ population scatter.

massive systems, the intrahalo gas is cold at all redshifts and it efficiently inflows to the galaxy (cold flows) in such a way that the intrahalo gas-to-galaxy mass ratio strongly decreases with time (left panel, Fig. 1).

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